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Experimental investigations on fuzzy logic for process control

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Abstract

The present work is concerned with the design and experimental testing of fuzzy algorithms for the on-line control of a few processes: temperature of a methyl methacrylate batch polymerization reactor, evaporating and condensing temperatures of a refrigeration system and the overhead composition of a batch distillation column. PID-fuzzy algorithms were developed and compared to conventional PID controllers, proving to be more suitable and reliable for the polymerization process. For the batch distillation column, fuzzy control reduced the batch time and the energy consumption. The PID-fuzzy also outperformed the conventional PID in terms of energy savings for the refrigeration system.

Keywords: Fuzzy control; Batch distillation; Polymerization; Chiller; Refrigeration

1. Introduction

Fuzzy control has found wide applications over the past few years, raising the interest of control equipment manufacturers. According to Ljung (1996), there are a number of reasons for the "popularity" of fuzzy control. First, real life control objects are nonlinear: their dynamics change with the operating point and there may be other essential nonlinearities in the process. This calls for regulators with nonlinearities. Traditionally, this has been dealt with by various *ad hoc* tricks, such as max selectors. A more advanced version is the adaptive control, including the gain scheduling, i.e., changing the controller parameters with the operating point. Changing control modes or parameters, depending on various signal levels, has been created case by case, reflecting the control designer insight into the control object properties. From the point of view of Ljung, what fuzzy control offers is a better user interface to this process of translating system insight into controller nonlinearities.

Fuzzy control may handle a large number of inputs, most of which are relevant only for some special conditions. Such inputs are activated only when the related condition prevails. Consequently, it can achieve proper control over a wide range of operating conditions.

The variety of fuzzy control applications indicates that this technique is becoming an important tool for complex processes (Lee, 1990). Recent fuzzy logic experimental applications are reported in the literature (Abdelazim & Malik, 2005; Börner & Isermann, 2006; Carvalho & Durao, 2002; Ewald, Delgado, & Becker, 2003; Li, Yang, Gao, & Wang, 2001; Souza Jr, Lopes, Pinto, Almeida, & Giordano, 2004).

From the above, fuzzy control is a promising way to solve industrial control problems. The use of these controllers in pilot-scale plants is essential to evaluate their potential value. The present work is concerned with the design and experimental testing of fuzzy control systems for temperature control in a methyl methacrylate (MMA) batch polymerization reactor, overhead stream composition control in a batch distillation column and temperature control in a refrigeration system.

The batch polymerization process is widely used in industries because of its operational flexibility. Due to its nonlinearity, complexity, variability and uncertainty, batch polymerization offers attractive and challenging problems concerning control. Regarding the MMA reactor, the

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Nomenclature

Δe	change-of-error
$(\Delta e)^2$	second change-of-error
Δu	change in control action
e	controlled variable error
EEC	electric energy consumption
GPC	gel permeation chromatography
ISE	integral of the square error
IAE	integral of the absolute error
ITAE	integral of the time-weighted absolute error
i, k	index of discrete points
K	scaling factor (gains)
min	minimum operator
N	negative membership function
OPC	OLE for process control
P	positive membership function
PLC	programmable logic controller
SISO	Single input single output
T	temperature
μ	membership function (activation level)
x	actual value of measured variable
y	Δu discrete point value
Z	zero membership function
z_0	defuzzified action value

major source of nonlinearity arises from the autocatalytic nature of the polymerization reaction (known as gel effect). It may lead to uncontrollable situations, resulting in excessive temperature rise, rapid increase in polymerization rate and equipment plugging (Soroush & Kravaris, 1993). A survey of advanced control for batch polymerization reactors is reported by Li and Wang (2004). According to these authors, there is a huge gap between industry and research practices. Aside from many theoretical developments, only a few papers describing experimental tests of closed-loop polymerization reactions are found in the literature (Chang & Liao, 1999; Jeong & Rhee, 2000; Pan & Lee, 2003).

Unsteady dynamics, finite-time operation, large thermodynamics uncertainty and nonlinear behavior make the control of batch distillation processes a challenging and interesting problem. Stenz and Kuhn (1993) described the implementation of fuzzy control in a batch column. The authors concluded from few experiments that automation presented the same performance using either conventional linear methods or fuzzy logic methodology. However, these authors mentioned that this control problem seems to be destined to fuzzy logic because the linguistic form knowledge available. Ruiz-Gomes, Lopes-Baldan, and Garcia-Cerzo (2000) reported a fuzzy modeling of a ternary batch distillation column. Yazdi, Bahar, Koggersbol, and Jorgensen (1995) presented a fuzzy control methodology for the start-up of a continuous distillation plant. Experimental investigation demonstrated that more than 25% of energy and time may be saved when using the new methodology compared to the manual implementation of the same process.

Over the last decade, the industrial, commercial and domestic refrigeration have undergone several conceptual and structural changes. The development of refrigeration systems, previously limited to mechanical and thermodynamic aspects, is now concerned with control systems and energy savings. The investigation of a fuzzy logic regulator for the performance improvement and the energy consumption of a simulated industrial chiller was reported by Barelli, Bidini, and Arce (2003). Since the compressor is responsible for the highest electrical energy consumption, a compressor control algorithm was developed. A fuzzy control of the compressor operation in a refrigeration plant is described by Aprea, Mastruollo, and Renno (2004). The main objective was to evaluate the energy savings obtained when the fuzzy algorithm to control the compressor refrigeration capacity replaced the classical thermostatic control, which imposes ON/OFF cycles to the compressor. The experimental results showed energy savings about 13%, using R407C as working fluid.

In this work, fuzzy control algorithms were developed and implemented on a computer and experimentally tested in a pilot distillation column and in a polymerization process in the *Automation and Process Control Laboratory* of the *School of Chemical Engineering* and also in a refrigeration process in the *Automation and Food Process Control Laboratory* of the *School of Food Engineering*, both in the *Campinas State University* (UNICAMP). The fuzzy control performance is compared to conventional feedback controllers. The conventional controller parameters were found via the Cohen–Coon method, from open-loop experiments, and by *Root Locus* stability analysis. Fuzzy control tuning was obtained by modifying the output scaling factor (gain), the cardinality and the membership functions for input and output variables.

2. Fuzzy control

The notion of fuzzy set is essential to explain the fuzzy control technique. The simplest way to understand the fuzzy set is by establishing its difference from an abrupt set, which belongs to classic logic domain. The relationship between an element and an abrupt set is of binary nature, i.e., the element is or is not a member. There is no intermediate state. To describe the membership of a given element, a special function is defined. It is called membership function and assumes two values: 0 (no member) and 1 (member). In contrast, a fuzzy set breaks this rigid relationship. The membership function may assume any values in the [0, 1] range.